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KEITHLEY INSTRUMENTS

INSTRUCTION MANUAL

MODEL 418A

REMOTE RANGING PICOAMMETER

WARRANTY

We warrant each of our products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof (except tubes and batteries) which, within a year after shipment, proves defective upon examination. We will pay domestic surface freight costs.

To exercise this warranty, call your local field representative or the factory, DDD 216-795-2666. You will be given assistance and shipping instructions.

REPAIRS AND RECALIBRATION

Keithley Instruments maintains a complete repair service and standards laboratory in Cleveland, and has an authorized field repair facility in Los Angeles.

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Estimates for repairs, normal recalibrations, and calibrations traceable to the National Bureau of Standards are available upon request.

SECTION 1. GENERAL DESCRIPTION

1-1. GENERAL.

a. The Keithley Model 418A Remote Ranging Picoammeter can be remotely controlled and it is ideally suited for external programming. It measures dc currents from 10^{-12} ampere full scale to 10^{-2} ampere. Rise time is 30 milliseconds on the 10^{-12} ampere range with no external capacitance across the input. Zero drift is less than 1% per 24 hours.

b. Current ranges on the Model 418A can be set using a front panel switch while the Model 4181 Input Head is either in the instrument chassis or at the signal source up to 100 feet away. Putting the input at the source eliminates long cable runs, minimizing input capacitance and preserving the fast rise time and low noise of the Picoammeter. Also, the Model 4185 Remote Switch may be mounted up to 1000 feet from the Model 418A to remotely control the Picoammeter range, whether or not the Input Head is in the chassis.

c. The Model 418A contains reed relays for use with external programming to control range selection. A 5-bit binary code, compatible with most computer outputs, is used to command range selection. All inputs require closure to chassis ground within 0.5 volt.

d. The Model 418A input has an electrometer tube for low noise at high impedances. Otherwise, solid-state components are used. The circuit is essentially a high-gain dc amplifier and a critically-damped feedback network. The Model 4181 Input Head contains the entire amplifier circuit, range resistors, reed relays and the logic circuitry.

1-2. FEATURES.

a. A front panel variable DAMPING Control increases the rise time approximately 3 seconds on the 10^{-12} to 10^{-8} ampere ranges and approximately 30 milliseconds on the 10^{-7} to 10^{-5} ampere ranges. The DAMPING Control helps achieve an optimum balance of response speed and noise to minimize 60-cps and external pick-up as well as noise from the source.

b. The Model 418A has a recorder output of ± 2 volts at up to 1 milliampere for a full-scale meter deflection on any range. Provision is made for lower voltage outputs also.

c. A ZERO CHECK Switch allows zeroing the meter on any range without disturbing the input circuit.

1-3. APPLICATIONS.

a. The Model 418A is designed to easily integrate into production test equipment. It conveniently and rapidly measures currents to 10^{-13} ampere, and a punched paper tape or other programmer can be used to select the ranges. The Picoammeter can be programmed to make several measurements per second. While the rate of measuring depends upon many factors (sensitivity, dynamic range, input capacity, etc.), switching between any two ranges can be done in 10 to 100 milliseconds under most conditions.

b. The Model 418A is very useful for nuclear reactor monitoring because of its remote input and control features. Fast, low-noise measurements are possible because the Input Head can be remotely located near the ion chamber, while the Picoammeter is controlled from the instrument chassis up to 100 feet away. Further, range selection and zero checking can be controlled up to 1000 feet from the chassis. A DAMPING Control allows a com-

promise between the fastest response speed and the lowest noise. If fast speed is not required and pick-up noise from external sources is unavoidable, the DAMPING Control will allow accurate measurements without noise. When equipped with the Model 4103 Electronic Trip, the Model 418A is adaptable to automatic reactor control.

c. Other applications are in low sweep rate mass spectrometry, noise studies, gas chromotography, flash filament testing, plasma physics studies and vacuum studies. The Model 418A can be used with photo-multipliers, mass spectrometers, ion chambers, flame and beta ray ionization detectors.

1-4. SPECIFICATIONS.

RANGE: 10^{-12} ampere full scale to 10^{-2} ampere in twenty-one 1x and 3x ranges, positive or negative currents.

RANGE SELECTION: Ranges may be selected at the main chassis location or from a remote location.

REMOTE CONTROL: Remote range switching requires a 5-bit binary input with binary "1" corresponding to the 10^{-2} ampere range in numerical order to binary "21" corresponding to the 10^{-12} ampere range. Zero check requires a separate input signal. All inputs require closure to chassis ground within 0.5 volt. Open circuit voltage is -15 volts; closed circuit current is 70 milliamperes maximum.

ACCURACY: $\pm$2% of full scale on 10^{-2} to 10^{-8} ampere ranges; $\pm$3% of full scale on 3 x 10^{-9} to $10^{\pm 2}$ ampere ranges.

ZERO DRIFT: Less than 1% of full scale per 24 hours on any range after a 30-minute warm-up and with source voltages greater than 1 volt.

ZERO CHECK: Allows zeroing without disturbing the circuit.

GRID CURRENT: Less than 3 x 10^{-14} ampere.

INPUT VOLTAGE DROP: Less than 1 millivolt for full-scale meter deflection on all ranges when properly zeroed.

EFFECTIVE INPUT RESISTANCE: 0.1 ohm on 10^{-2} ampere range, increasing to 1000 megohms on 10^{-12} ampere range in decade steps.

RISE TIME, MAXIMUM: Seconds, from 10% to 90%.

Range, ampere	No External Capacitance	With 50 pf Across Input	With 500 pf Across Input	With 5000 Across Input
10^{-12}	0.03	0.06	0.35	3.0
10^{-11}	0.006	0.01	0.035	0.3
10^{-10}	0.004	0.004	0.007	0.03
10^{-9}	0.004	0.004	0.006	0.01
10^{-8}	0.004	0.004	0.004	0.006
10^{-7} to 10^{-4}	Less than 1 millisecond			
10^{-3} to 10^{-2}	Less than 50 microseconds			

Note: Rise time may be lengthened by approximately 3 seconds on the 10^{-8} to 10^{-12} ampere ranges and by 30 milliseconds on the 10^{-5} to 10^{-7} ampere ranges with variable damping control.

RECORDER OUTPUT:

Output: ±2 volts at up to 1 milliampere for full-scale meter deflection. Output polarity is opposite input polarity. Provision is made for lower voltage outputs.

Resistance: Less than 1 ohm.

Noise: Less than 3% rms of full scale on 10^{-12} ampere range at minimum damping, decreasing to 0.3% rms with maximum damping.

CONNECTORS: Input: Teflon-insulated uhf type. Output: Amphenol 80-PC2F. Remote: Cannon DA15S. Remote Control: Winchester XAC 34-S-F-2-A-006.

POWER: 105-125 or 210-250 volts (switch selected), 50-1000 cps, 22 watts.

DIMENSIONS, WEIGHT: 5-1/4 inches high x 19 inches wide x 13-1/2 inches deep; net weight, 25 pounds.

ACCESSORIES SUPPLIED: Mating input and output connectors.

1-5. ACCESSORIES. The following accessories may be used to increase the measurement convenience of the Model 418A. Refer to Section 2 for operating and installing instructions unless otherwise noted.

a. Model 3000 Bench Mounting Kit converts the Picoammeter from a rack-mounted unit to one suitable for bench use. The Kit contains four feet with ball inserts, tilt bail and a hooded top cover. As a bench model, the Model 418A is 5-1/2 inches high x 17-1/2 inches wide x 13-1/2 inches deep. Section 6 contains assembly instructions and the parts list.

b. Model 4172 Remote Housing provides a firm base for the Model 4181 Input Head. Four 1/4-inch diameter mounting holes are on the base flange to facilitate attaching the Housing to another surface. The Housing is 5-1/2 inches high x 5-1/8 inches wide x 12-3/4 inches deep; net weight is 5 pounds.

c. Model 4183 Remote Amplifier Cable is required to connect the Input Head to the Picoammeter chassis for remote operations. The Cable is not sensitive to movements or normally encountered magnetic and electrostatic fields. The polyvinyl chloride outside jacket will resist most chemicals, solvents and oils. Standard cables, complete with locking connectors, are

Model Number	Length
4183-10	10 feet
4183-25	25 feet
4183-100	100 feet

Lengths up to 500 feet are available on special order. (See paragraph 2-6.)

NOTE

Use of the Model 4183 Cable will lengthen rise times on the most sensitive ranges. (See paragraph 2-9).

d. Model 4184 Remote Control Cable is 25 feet long with a connector to mate with the Model 418A REMOTE CONTROL Receptacle. The other end has tinned leads to connect with

either the Model 4185 Remote Switch or the output terminals of the device used to program the Picoammeter. The Cable may be lengthened up to 1000 feet using wire of the same guage. Longer lengths are possible if a lower guage is used.

e. Model 4185 Remote Switch provides a range switching sequence identical to the front panel Range Switch. It is a small rotary switch available for mounting in prime panel space, which allows manual range control up to 1000 feet from the chassis. The Switch is 2-1/2 inches in diameter by 2 inches deep.

f. Model 6106 Electrometer Connecting Kit provides useful adapters, leads and a tee for use with the Model 418A. The accessories, contained in a convenient case, are described in Section 6.

1-6. EQUIPMENT SHIPPED. The Model 418A Remote Ranging Picoammeter is factory-calibrated and is shipped with all components in place. It is shipped with separate rack angles for rack mounting. Refer to Section 6 for assembly instructions. The shipping carton also contains the Instruction Manual and mating plugs for the input and output receptacles.

SECTION 2. OPERATION

2-1. FRONT PANEL CONTROLS.

a. METER Switch. The METER Switch has four positions. The POWER OFF position shuts the instrument off. The OFF position disconnects the meter for recorder operation; only the meter circuit in the Model 418A is not operating. The two polarity positions, + and -, set the meter polarity.

b. ZERO Control. The 10-turn ZERO Control allows precise meter adjustment to zero on any range when either the ZERO CHECK Switch is depressed or the Range Switch is in ZERO CHECK position.

c. Range Switch. The Range Switch, marked AMPERES FULL SCALE, is located on the Model 418A main chassis. It adjusts the meter sensitivity over 21 ranges from 10^{-12} to 10^{-2} ampere. The Range Switch operates only when the CONTROL Switch is set to LOCAL. The ZERO CHECK position on the Range Switch is for use on the 10^{-6} ampere and higher ranges.

d. ZERO CHECK Switch. The ZERO CHECK Switch is a positive action, push-button switch. Depressing the Switch effectively removes all current from the amplifier input and allows meter zeroing on the 3×10^{-7} ampere and lower ranges. Use the ZERO CHECK position on the Range Switch for the higher ranges.

e. CONTROL Switch. The 2-position CONTROL Switch selects either LOCAL control for range selection using the Range Switch on the chassis, or REMOTE control for external range selection or programming.

f. DAMPING Control. The DAMPING Control adjusts the damping of the feedback circuit from minimum (critical) to a maximum additional rise time of 3 seconds on the 10^{-12} to 10^{-8} ampere ranges and of 30 milliseconds on the 10^{-7} to 10^{-5} ampere ranges. Turning counter-clockwise to the MIN position locks the Control in the critical damping position. Turning the Control clockwise increases damping (increases the rise time).

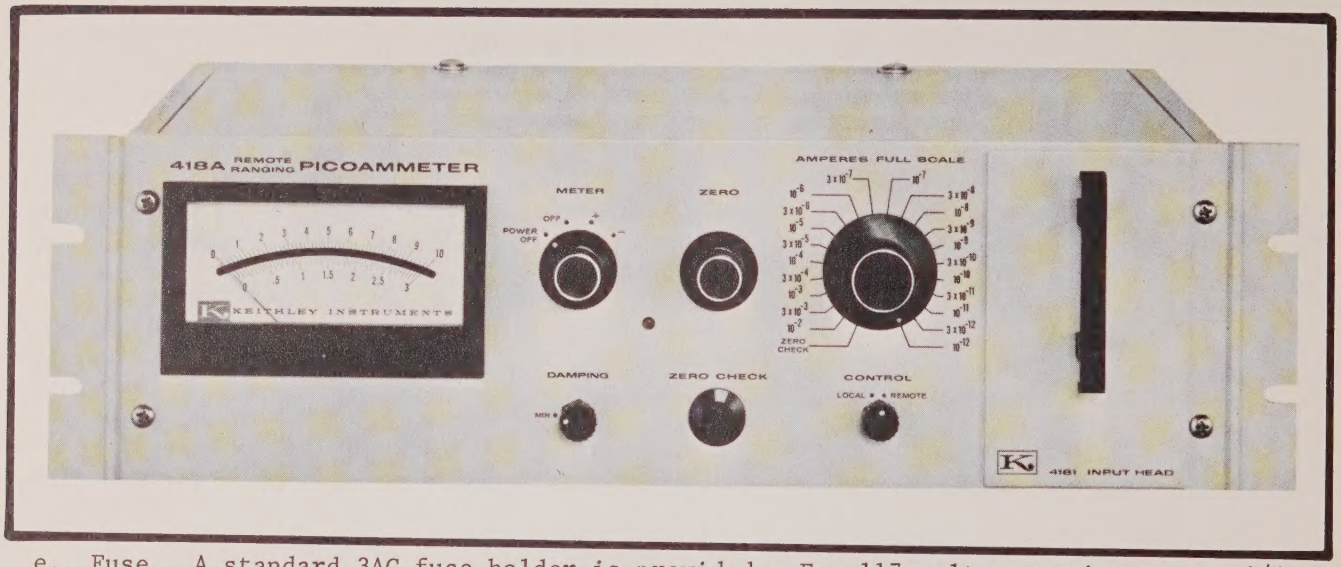
2-2. REAR PANEL TERMINALS.

a. J101 INPUT Receptacle. A Teflon-insulated uhf-type coaxial input receptacle is on the back of the Model 4181 Input Head. It is accessible from the rear of the chassis when the Head is in place.

b. J202 REMOTE Receptacle. A 15-contact receptacle is the mate for one end of the Model 4183 Remote Cable, used to connect the Input Head to the Picoammeter for remote measurements. A slide-lock retainer prevents accidental removal of the connector.

c. J203 OUTPUT Receptacle. A 2-terminal receptacle supplies 2 volts at full-scale meter deflection on all ranges. Pin no. 2 is at chassis ground potential. Output polarity is opposite the input signal polarity. Provision is made for other voltage outputs on special order.

d. Remote Control Receptacle. This is a 34-contact Winchester receptacle on which 10 contacts are used. It allows range selection on the Model 418A from a remotely located range switch or programmer. The CONTROL Switch must be set to REMOTE to use the controls connected to the Remote Control Receptacle. See paragraph 2-6 for the connections.



e. Fuse. A standard 3AG fuse holder is provided. For 117-volt operation, use a 1/2-ampere, 3AG slow-blow fuse; for 234-volt, use a 1/4-ampere, 3AG slow-blow fuse.

f. Power Cord. The 3-wire power cord with the NEMA approved 3-prong plug provides a ground connection for the cabinet. An adapter for operation from two-terminal outlets is provided.

g. 117-234 Switch. The screwdriver operated slide switch sets the Picoammeter to operate from 117 or 234-volt ac power lines.

2-3. INPUT CONNECTIONS. The following considerations apply to connecting the current source to the J101 INPUT Receptacle, whether the Input Head is in the Model 418A or remotely located. Refer to paragraph 2-6 for remote operation procedures.

NOTE

Using coaxial cables and the Model 6106 Kit accessories is the best way to make input connections.

a. Carefully shield the input connection and the current source, since power line frequencies are well within the Picoammeter pass band on all ranges. Unless the shielding is thorough, any alteration in the electrostatic field near the input circuitry will cause definite meter disturbances. If power line frequencies cannot be eliminated at the current source, use the DAMPING Control to attenuate these frequencies, so that the dc or low-frequency measurements can still be made (see paragraph 2-4, e).

b. Use high resistance, low-loss materials — such as Teflon (recommended), polyethylene or polystyrene — for insulation. The insulation leakage resistance of test fixtures and leads should be several orders magnitude higher than the internal resistance of the source. If it is not, leakage losses will cause lowered readings. Coaxial cable used should be a low-noise type which employs a graphite or other conductive coating between the dielectric and the surrounding shield braid. Amphenol-Borg Electronics Corporation, Microdot, Inc., and Simplex Wire and Cable Company make satisfactory types. Using low-noise cable is necessary because the Model 418A has a wide frequency range.

NOTE

Clean and dry connections and cables are very important to maintain the value of all insulation materials.

c. Any change in the capacitance of the measuring circuit to ground will cause extraneous disturbances. Make the measuring setup as rigid as possible, and tie down connecting cables to prevent their movement. If a continuous vibration is present, it may appear at the output as a sinusoidal signal; other precautions may be necessary to isolate the instrument and the connecting cable from the vibration.

NOTE

Techniques and applications are thoroughly discussed in the booklet, Electrometer Measurements, by Joseph F. Keithley. It is available by writing Keithley Instruments, Inc., or its representative.

2-4. LOCAL OPERATING PROCEDURES. The following procedures apply when operating the Model 418A from the front panel controls on the chassis. The Model 4181 Input Head may either be in the chassis or remotely located; see paragraph 2-5 for additional instructions for setting up and using the Input Head remote from the Model 418A chassis.

a. Set the CONTROL Switch to LOCAL and the Range Switch to ZERO CHECK. Check the 117-234 Switch for proper line voltage setting. Connect the power cord to the power line. Turn the instrument on by setting the METER Switch to OFF. For best zero stability, allow 5 minutes for warm-up.

b. Set the METER Switch to either + or -; adjust the meter with the ZERO Control for a zero reading.

c. Connect the current source to the J101 INPUT Receptacle; observe the precautions listed in paragraph 2-3.

d. Set the METER Switch to the input signal polarity. Advance the Range Switch clockwise until an on-scale reading is obtained in the upper two-thirds of the meter scale. If a range below 10^{-6} ampere is used, recheck meter zero by depressing the ZERO CHECK Switch.

NOTE

On the 10^{-2} to 10^{-6} ampere ranges, check meter zero by setting the Range Switch to ZERO CHECK. On the 3×10^{-7} to 10^{-12} ampere ranges, check meter zero using the ZERO CHECK Switch. Using these Switches to check zero will not disturb the input circuit.

e. If extraneous fields produce rapid vibrations of the meter pointer, turn the DAMPING Control clockwise from its MIN position until the vibration stops. Although this decreases the Model 418A frequency response, dc measurements may still be made with no accuracy decrease. The damping control is in the circuit only when the Range Switch is set to the 10^{-5} ampere and lower ranges.

2-5. REMOTE HEAD OPERATION. The shunt capacitance caused by long cable runs to the input will considerably lengthen response time and increase noise. To maintain short rise times and to reduce noise, place the Input Head at the signal source. Distance between the Model 418A chassis and the Model 4181 Head can be up to 100 feet.

a. To remove the Input Head from the main chassis, remove the cap from the J101 INPUT Receptacle and unscrew the captive retaining screw on the back panel. Pull the Input Head from the chassis, using the handle mounted on its front panel.

b. The Model 4172 Remote Housing provides a secure mounting for the Input Head, although it is not necessary for remote measurements. If the Model 4172 is used, insert the Model 4181 into the Housing. The captive screw on the rear of the Housing secures the Input Head in place. Access holes are located at the rear of the Housing for all connections.

c. Connect the Input Head to the J202 REMOTE Receptacle on the Picoammeter, using the Model 4183 Remote Amplifier Cable. Secure the plugs on the Cable to the mating receptacles with the slide-lock retainers. The Model 4183 is not sensitive to normally encountered movements or magnetic and electrostatic fields. It will not decrease the accuracy of the measurement. However, use of the Model 4183 Cable will lengthen the rise time on the most sensitive ranges (paragraph 2-9). Individual cable lengths may be connected together; the longest recommended total cable length is 100 feet.

NOTE

Use only the Model 4183 Remote Cable to connect the Input Head to the Model 418A.

d. Model 418A operation with the Input Head located at the source is identical to the procedures in paragraph 2-4.

e. To return the Model 4181 Head into the chassis, position the nylon glides on the Head into the chassis. Slide the Head inward until its front is flush with the Model 418A front panel. Secure the chassis with the retaining screw provided.

2-6. REMOTE RANGING OPERATION. The Model 418A range selection and zero checking can be controlled up to 1000 feet from the Picoammeter chassis. The control can be through either the Model 4185 Remote Switch or a programming device. The Input Head may be either in the chassis or remotely located at the signal source when the Model 418A is set to remote ranging operation.

a. Connect the remote ranging control facility — a programming device or the Model 4185 Switch — to the Model 418A Remote Control Receptacle with the Model 4184 Remote Control Cable. One end of the Cable has the mating plug to the receptacle and the other end has stripped and tinned leads to connect to the controlling device.

b. Table 1 lists closures to ground necessary to program the ranging. The inputs are for the lettered terminals in the Remote Control Receptacle on the Model 418A rear panel. Terminal g is ground. Closure of terminal Z to ground activates the zero check circuit on any range.

c. Set the CONTROL Switch to REMOTE. If desired connect indicator lamps to show the CONTROL Switch position. Connect the lamps between terminals L and g and between R and g of the Remote Control Receptacle. Each connection provides +15 volts at up to 150 milliamperes.

d. Table 2 lists all terminal connections on the Remote Control Receptacle. Inputs A through E and Z require closure to ground, g, within 0.5 volt. Open circuit voltage is -15 volts; closed circuit current is 70 milliamperes maximum. An external output of ±3 volts for full-scale meter deflections is available between terminals M and g. This output is the same as that through the J203 OUTPUT Receptacle.

Position	Range Switch Setting	Relays Energized	J204 Contacts; 1 = Closed, 0 = Open A	B	C	D	E	Z
1	Zero Check	K101, 102, 111, 112, 113, 114	0	0	0	0	1	1
2	10^{-2}	K111, 112, 113, 114	0	0	0	0	1	0
3	$3x10^{-3}$	K111, 112	0	0	0	1	0	0
4	10^{-3}	K111, 112, 114	0	0	0	1	1	0
5	$3x10^{-4}$	K111	0	0	1	0	0	0
6	10^{-4}	K111, 114	0	0	1	0	1	0
7	$3x10^{-5}$	K110	0	0	1	1	0	0
8	10^{-5}	K110, 114	0	0	1	1	1	0
9	$3x10^{-6}$	K109	0	1	0	0	0	0
10	10^{-6}	K109, 114	0	1	0	0	1	0
11	$3x10^{-7}$	K108	0	1	0	1	0	0
12	10^{-7}	K108, 114	0	1	0	1	1	0
13	$3x10^{-8}$	K107	0	1	1	0	0	0
14	10^{-8}	K107, 114	0	1	1	0	1	0
15	$3x10^{-9}$	K106	0	1	1	1	0	0
16	10^{-9}	K106, 114	0	1	1	1	1	0
17	$3x10^{-10}$	K105, 115	1	0	0	0	0	0
18	10^{-10}	K105, 114, 115	1	0	0	0	1	0
19	$3x10^{-11}$	K104, 105	1	0	0	1	0	0
20	10^{-11}	K104, 114, 115	1	0	0	1	1	0
21	$3x10^{-12}$	K103, 115	1	0	1	0	0	0
22	10^{-12}	K103, 114, 115	1	0	1	0	1	0

TABLE 1. Input Table for Model 418A Range Selection. The letters refer to the lettered terminals on the Remote Control Receptacle, J204. Contact g is ground.

TERMINAL	FUNCTION	TERMINAL	FUNCTION
A	Input A	g	Ground
B	Input B	L	+15 volts when CONTROL Switch is set to LOCAL.
C	Input C		
D	Input D	M	$\pm$3 volts for full-scale deflection.
E	Input E	R	+15 volts when CONTROL Switch is set to REMOTE.
		Z	Input Z

TABLE 2. Wiring for Remote Control Receptacle (J204).

e. Range switching time is 10 to 100 milliseconds maximum, depending upon the actual ranges involved.

2-7. RECORDER OUTPUT. The output of the Picoammeter for full-scale deflection on any range is 3 volts at up to 1 milliampere. The output polarity is the opposite of the input signal polarity. One-milliampere Esterline-Angus and Texas Instruments recorders may be

driven directly. Pin no. 2 is ground. The METER Switch does not reverse the output polarity. To drive 10 and 50-millivolt recorders, divide the output with a suitable network on the power supply pc board. A 50-millivolt output at 100 ohms is available if ordered instead of the 3-volt output.

2-8. NOISE. Rms output noise is less than 60 millivolts on the most sensitive range with the DAMPING Control in minimum position. Advancing the DAMPING Control from its locked critical position will greatly decrease this noise while increasing the rise time.

2-9. RISE TIME.

a. As indicated in the specifications, rise time increases with input capacity. Although the input capacity is minimized by locating the Input Head at the source, some is introduced by any connection used. The curves shown in Figure 4, indicate the rise times (from 10% to 90% of final value) for various input capacities and cable lengths.

b. Rise time for the Model 418A is specified with the Head mounted in the main chassis. When the Head is removed and connected to the main chassis by a length of Model 4183 Cable the rise time will lengthen on the most sensitive ranges. Table 3 shows maximum rise times to be expected on these ranges when using different lengths of the Model 4183 Cable. The approximate maximum rise time with external capacitance is given by

Range, ampere	Model 4183 Cable Length 10 ft.	25 ft.	100 ft.
10^{-12}	.060	.100	.300
10^{-11}	.012	.020	.060
10^{-10}	.008	.014	.040
10^{-9}	.004	.007	.020

TABLE 3. Maximum Rise Times to be Expected on the Most Sensitive Ranges With Different Lengths of the Model 4183 Cable.

$$\text{Maximum rise time} \cong \sqrt{\left[(\text{range constant}) \times (\text{4183 length in feet})\right]^2 + \left[\begin{array}{l}\text{specified}\\ \text{rise time}\\ \text{with head}\\ \text{in chassis}\end{array}\right]^2}$$

where the range constants are:

Range	Constant
10^{-12}	.003
10^{-11}	.0006
10^{-10}	.0004
10^{-9}	.0002

c. If higher speed on the low ranges is necessary with remote head mounting, the rise time can be brought to within twice the "head-in instrument" specifications by changing R-142 from its present value of 560 ohm to 3.3 k ohm. The resistor can be of the standard 1/2 watt carbon variety. This change, however, prevents the instrument from operating on ranges above 10^{-4} amperes.

2-10. 234-VOLT OPERATION. The instrument is shipped for use with a 117-volt power source unless otherwise ordered. To convert the Model 418A for 234-volt sources, use a screwdriver to change the 117-234 Switch on the rear panel. Change the fuse from 0.5 amp to 0.25 ampere. No other adjustment is necessary. To switch from 234 to 117-volt operation, reverse the procedures. The Model 418A operates from 50 to 1000 cps without adjustments.

SECTION 3. CIRCUIT DESCRIPTION

3-1. GENERAL. The Model 418A Remote Ranging Picoammeter consists principally of a high-gain dc amplifier with a range selector circuit and a critically damped feedback network. See Figure 5. These are powered by a super-regulated dc power supply. The range selector circuit contains reed relays, range resistors, and the logic circuitry for operating the relays. The Model 418A contains all the switch and connector circuitry needed for remotely operating the Input Head at the signal source, to remotely select ranges, and for external programming of range selection.

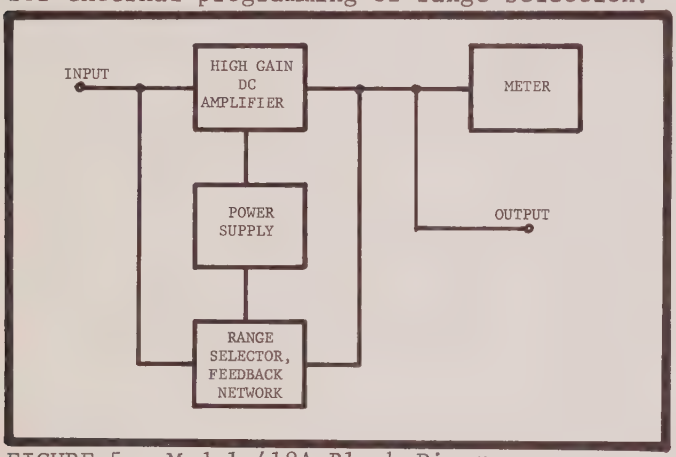


FIGURE 5. Model 418A Block Diagram.

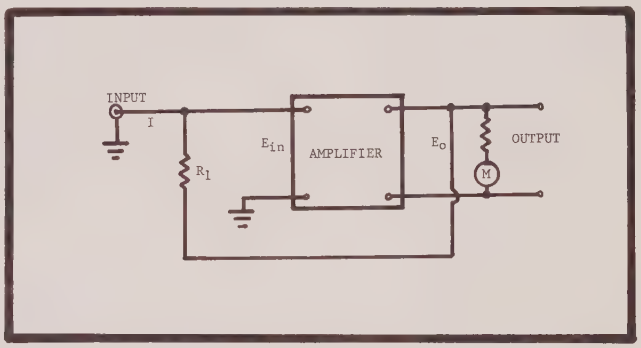


FIGURE 6. Simplified Amplifier and Feedback Circuit. R_1 is the feedback or range resistor. E_{in} is the voltage across the amplifier input; E_o is the voltage across the amplifier output.

3-2. AMPLIFIER AND FEEDBACK. The amplifier with feedback circuit is shown in Figure 6. The feedback or range resistor, R_1, is in the feedback circuit for fast instrument response; the value of the resistors depends upon the range being used. The amplifier output is the negative of the input signal. Assuming no current flow into the amplifier input, the input current, I, will flow through the feedback resistor, R_1. If the gain of the amplifier is k and the feedback is negative, then

$$E_{in} = E_o/k \qquad \text{Equation 1}$$

where E_{in} is the voltage across the amplifier input;
E_o is the voltage across the amplifier output;
k is the open-loop amplifier gain.

Since the current must flow through R_1,

$$I = \frac{-E_o + E_o/k}{R_1} \qquad \text{Equation 2}$$

If the gain is large — the Model 418A gain is greater than 10,000 — then the current flow is

$$I = -E_o/R_1 \qquad \text{Equation 3}$$

and a voltmeter at the amplifier output may be calibrated to read current directly.

a. High Gain DC Amplifier. The amplifier consists of an electrometer tube input stage, an emitter follower input, a 2-stage transistor amplifier and an emitter follower output.

NOTE

Refer to Schematic Diagrams 17931D and 18406F for circuit designations.

1. The input signal is applied to the grid of the electrometer tube, V101, through an overload network, capacitor C109 and resistor R122. An electrometer tube is used at the input because of its low noise characteristics at high impedances. Plate voltage for V101 is supplied through resistor R124; the 10-milliampere filament current is obtained from the +15 volt power supply output through resistors R125 and R128. Adjusting potentiometers R127 and R205 zeroes the meter by changing the screen voltage of the electrometer tube.

2. The electrometer tube is connected directly to the emitter follower transistor, Q101. For the 10^{-2} to 10^{-9} ampere ranges, resistor R123 and capacitor C110 operate to prevent oscillations due to amplifier instability. The output of transistor Q101 is directly coupled to the first stage amplifier, transistor Q102. Identical transistors, Q103 and Q104, provide temperature compensation for the 2-stage amplifier. Resistor R134 determines the first stage gain by varying the emitter degeneration of transistor Q102. The collector of Q102 is directly coupled to the base of the second stage amplifier, transistor Q105. On the 3×10^{-8} to 10^{-12} ampere ranges, zener diode D101 stabilizes emitter bias; an RC network, capacitor C111 and resistor R131, between the base and collector of transistor Q105 prevents oscillations.

3. The output of transistor Q105 is directly coupled to the base of the emitter follower output stage, which uses a power-type transistor, Q106. The amplifier output is applied through resistors R217 and R218 to the meter, M201, and to two recorder outputs, J203 and terminal M of J204. The collector of Q106 and the second stage amplifier collector resistor, R149, are returned to the -15 volt power supply output to permit positive and negative outputs. Diode D102 and resistor R141 prevent overloading of the output stage.

b. Feedback Network.

1. The feedback network consists of the range resistor, relay K114 and dividers R115 and R116. The relay and divider resistors divide the 2-volt amplifier output at full scale to 1 volt.

2. Having the range resistor in the feedback network allows faster response speeds by minimizing the effects of input capacity and also reduces the Model 418A input voltage drop. Range resistors for the 10^{-12} to 10^{-5} ampere decade ranges are R101 to R108, respectively. For ranges above 10^{-5} ampere and for the ten 3x ranges, the range resistors are R117 to R121, used in various combinations.

c. Damping.

1. Referring to Figure 7, which shows a simplified Model 418A amplifier circuit, the time constant, T, is

$$T = R_1 \quad \frac{C_1}{1 + k} + C_2 \qquad \text{Equation 4}$$

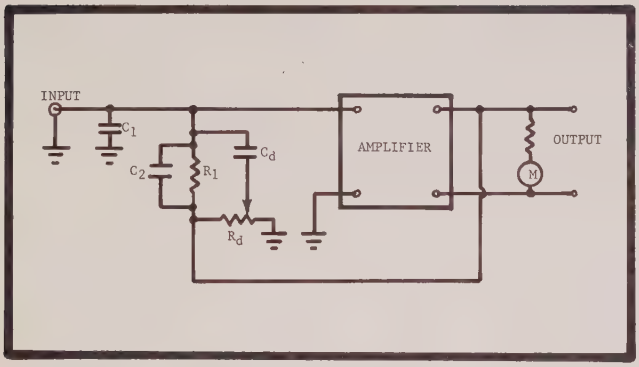


FIGURE 7. Feedback Network with Capacitance Indicated. C_1 is the input capacity; C_2 is the capacity across the range resistor; R_1 is the range resistor; C_d is the damping capacitance; R_d is the damping resistance.

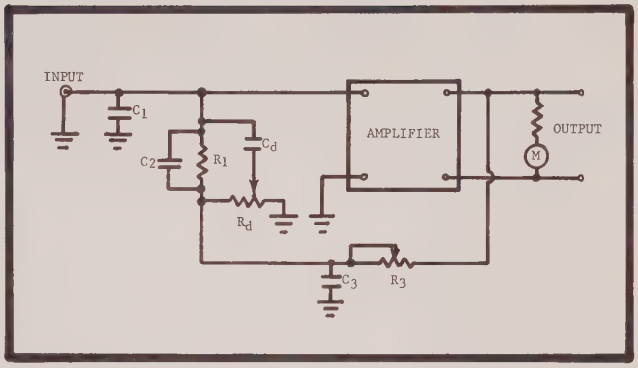


FIGURE 8. Critically Damped Feedback Network. R_3 and C_3 are added to the circuit shown in Figure 7; their values are such that $R_3C_3 = R_1C_2$.

where C_1 is the input capacity;
R_1 is the range or feedback resistance in ohms;
C_2 is the capacity across the range resistor;
k is the open-loop amplifier gain.

Since the amplifier gain is greater than 10,000, the effect of the input capacity on the time constant is very small — except at very low currents — and the product R_1C_2 primarily determines the time constant. With a 10^{12} ohm resistor, which is used on the most sensitive range, this product can amount to 10 seconds.

2. To decrease the effect of R_1C_2, resistor R_3 and capacitor C_3 are added to the circuit. See Figure 8. If $R_3C_3 = R_1C_2$, a lead network cancels a lag network. Equation 4 now becomes

$$T = \frac{R_1 (C_1 + C_2)}{1 + k} \qquad \text{Equation 5}$$

where both capacities are degenerated by loop gain. With this arrangement, the circuit is critically damped. Adding more input capacity affects the time constant, but not the critical damping, since basically the circuit is a single time-constant feedback system.

3. The DAMPING Control, R222 and S206, are in the circuit for the 10^{-12} to 3×10^{-5} ampere ranges. When the DAMPING Control is at MIN, the Picoammeter rise time is the shortest (fastest response speed). Increasing damping lengthens the rise time by approximately 3 seconds on the 3×10^{-8} to 10^{-12} ampere ranges and by approximately 30 milliseconds on the other ranges. A damping capacitor, C114 to C120, is connected between the DAMPING Control and each range resistor, R102 to R108. The damping capacitor on the most senstive range is a fabricated brass band placed on range resistor R101.

3-3. RANGE SELECTOR CIRCUIT.

a. The Model 418A range selection is controlled either directly from the chassis with the Range Switch, S204, or externally with the Model 4185 Remote Switch or a programming device. The external control connects to the Picoammeter through the Remote Control Receptacle, J204. The position of the CONTROL Switch, S203, determines if switch S204 or receptacle J204 is in the circuit. The range selector circuit operates the same for both.

b. Reed relays K103 through K110 connect the proper range resistor into the feedback network for the 10^{-12} to 10^{-5} ampere decade ranges. The relays ground or connect to the chassis all unused range resistors while connecting the used range resistor to the input. Relays K111 to K114 select the proper range resistors for the higher current ranges. For the 3x ranges from 3×10^{-11} to 3×10^{-5} ampere, the feedback voltage is 2 volts at full scale. Switching of the feedback voltage is controlled by a telephone-type relay, K114, which also is used for range resistor selection on the higher ranges.

c. Reed relay K101 and relay K102 are used for the zero check circuit. When these relays are energized, the Model 418A input is connected directly to the output. The instrument can then be zeroed even with an input current present. Resistors R146 and R147 prevent transients from appearing at the amplifier output during this time. Relay K102 also connects an RC network, resistor R123 and capacitor C110, into the amplifier circuit to prevent oscillations.

d. Relay K115 is activated on the most sensitive ranges to connect the proper RC network, capacitor C110 and resistor R123 or capacitor C111 and resistor R131, for the best amplifier stability.

e. Capacitors shunt range resistors R105 to R108 to prevent over-peaking when a current step input is applied.

f. Diodes D103 to D113, D115 and D118 shunt the relay coils. The diodes clamp at a safe level the voltage induced by the relay coils when they are de-energized. This eliminates transients in the amplifier output and protects the relay coil driving transistors in the logic circuit.

3-4. LOGIC CIRCUIT. The Input Head contains a binary coded decimal (BCD) converter to change the 5-bit binary coded decimal range selection inputs into decimal outputs for operating the various range selector relays. The entire BCD converter is on printed circuit board PC 97. Direct coupled transistor logic is used in this circuit for simplicity and to drive the relay coils directly. Transistors Q302, Q305, Q310 and Q319 are inverter transistors for the logic circuit. Diodes D304 to D307 allow more than one logic board to be connected in parallel at the inputs without interaction. This occurs when another instrument is operated simultaneously from the same range switch. Diode D308 prevents circuit interaction when relay K112 is operated by another contact on relay K113 and not by the logic circuit. Diodes D301 to D303 assure complete cutoff of the transistors at high temperatures.

3-5. POWER SUPPLY. The power supply furnishes +15 and -15 volts to the amplifier and -15 volts to the relay coils and logic circuit. Long term dc stability of the +15 volt supply is within 0.1%. Output variations are less than 0.001% for 10% line voltage changes.

a. A 24-volt, 1-ampere output from the transformer, T201, is rectified by diodes D203 and D204, filtered by capacitor C202, and applied to the series transistor, Q204. The potential across capacitor C202 is approximately 23 volts dc.

b. To obtain a stable, accurate voltage, the output of the series transistor, Q204, is regulated by comparing a sample voltage from dividers R215 and R216 to the zener diode reference, D208. Any voltage difference is amplified by a differential amplifier consisting of transistors Q206 and Q207. The signal is further amplified by transistors Q205, Q202 and Q203. The output of Q203 is applied to transistor Q204 to nullify input variations. Capacitor C206 prevents high frequency oscillations. The +15 volts at the output of the regulator powers the filament of electrometer tube, V101, and the pilot lamp. Also

+15 volts is used to operate the CONTROL Switch indicator lights, if these are used.

c. Transistor Q205 operates at a high gain by connecting its collector load to a regulated negative supply. The circuit permits linear operation of transistor Q204 with widely varying input voltages. To supply transistor Q205, a 24-volt output of transformer T201 is full-wave rectified by diodes D201 and D202 and is filtered by capacitor C201. Resistor R202 and capacitor C203 provide another section of filtering. The -26.5 volt output is applied to a series transistor regulator, Q201, with zener diode D205 serving as the voltage reference. Capacitor C204 is connected across diode D205 to further reduce output ripple. Capacitor C205 is the final output filter.

d. Transistors Q202 and Q203 are cascaded emitter followers whose function is to increase the current gain of the series transistor, Q204. Resistors R206 and R209 are added to the circuit to provide stability at high temperatures. Resistors R210 and R211 and Diode D206 provide current overload protection should the +15 volt supply be accidentally shorted. Excessive current drawn from the power supply causes an increased voltage drop across resistor R210 which forward biases diode D206, thus preventing the collector of transistor Q205 from going more negative. Since the collector voltage cannot rise, further amplification is prevented and, therefore, further current increase is prevented.

SECTION 4. SERVICING

4-1. GENERAL. Section 4 contains the maintenance and troubleshooting procedures for the Model 418A Remote Ranging Picoammeter. Follow these procedures as closely as possible to maintain the instrument's accuracy and high performance.

4-2. SERVICING SCHEDULE.

a. The Model 418A requires no periodic maintenance beyond the normal care required of high-quality electronic equipment. No part should need replacement under ordinary use except the pilot lamp or the fuse.

b. Check the value of the high megohm resistors, R101 through R104, every two or three years. This is easily done by checking the Model 418A accuracy on the 10^{-9} to the 10^{-12} ampere decade ranges. Occasional verification of the accuracy on any range, using the Model 261 Picoampere Source, will show the need for any adjustment. If necessary, recalibrate the Picoammeter; see Section 5.

4-3. PARTS REPLACEMENT.

a. The Replaceable Parts List in Section 7 describes the electrical components of the Picoammeter. Replace components only as necessary. Use only reliable replacements which meet the specifications. The instrument uses no special components except for those listed in the following subparagraphs.

b. The high megohm range resistors, R101 through R104 (Figure 17), are specially selected and aged to assure the specified Model 418A accuracy. In normal use they do not need replacement. If replacement becomes necessary, however, order the resistors only from

Instrument	Use
General Radio Variac	Check power supply regulation
Keithley Instruments Model 261 Picoampere Source, outputs from 10^{-14} to 10^{-4} ampere, accuracy from $\pm$0.25% to $\pm$0.6%	Check accuracy of ranges. Check high megohm resistors
Keithley Instruments Model 4183 Remote Amplifier Cable	Connect Input Head to chassis
Keithley Instruments Model 610B Electrometer; 1 millivolt to 100 volts, 10^{14} ohm input resistance, $\pm$1% accuracy; 100 Ω full scale to 10^{14} Ω	Measure dc voltages. Check resistors through reed relay assemblies.
Keithley Instruments Model 660A Guarded dc Differential Voltmeter, $\pm$0.02% limit of error	Check power supply regulation
Tektronix Type 561A Oscilloscope	Monitor voltages

TABLE 4. Equipment Recommended for Model 418A Servicing. Use these instruments or their equivalents.

Keithley Instruments, Inc., or its representative. In an emergency, the resistors may be obtained from another distributor, but their stability may not be adequate. In either case, recalibrate the Model 418A after replacing a range resistor on any range.

NOTE

When replacing the range resistors, R101 through R104, do not touch the glass body. Contamination of the specially coated glass insulation will occur, and leakage will result.

c. The electrometer tube, V101, is aged; order a replacement for it only from Keithley Instruments, Inc., or its representative. Transistors Q102 and Q103 are matched to each other, as are transistors Q101 and Q104. The pairs are matched for beta for temperature stability of the amplifier. Replace any of these transistors as pairs ordered through Keithley Instruments, Inc.

d. The reed relay assemblies K103 through K111 are manufactured by Keithley Instruments. In each assembly, two form-A reed relays are connected together at one end; one relay is biased with a small permanent magnet. The entire assembly is then a form-C reed relay with very good leakage characteristics. High resistance between ends is absolutely necessary if accuracy and zero stability of the Model 418A is to be maintained.

Trouble	Probable Cause	Solution
One range out of calibration	High megohm resistor for range is not within specifications	Refer to paragraph 5-3
Meter will not zero	Potentiometer R127 is out of adjustment	Refer to paragraph 5-4
Meter out of calibration	Potentiometer R218 is out of calibration	Refer to paragraph 5-4
	Tube V101 or transistor Q101, Q102 or Q105 is faulty	Check transistors; replace if faulty. Check V101 against Table 5 values
Rise time excessive on one range	Potentiometer R109, R111 or R112 out of adjustment	Refer to paragraph 5-5
Meter oscillates on 10^{-2} to 3×10^{-10} ampere ranges	Resistor R123 or capacitor C110 faulty	Check parts; replace if faulty
Meter oscillates on 3×10^{-10} to 10^{-12} ampere ranges	Resistor R131 or capacitor C111 faulty	Check parts; replace if faulty
Meter zero is very critical or sensitive	Feedback loop shorted because of faulty reed relay assembly	Check K103 to K111; replace if faulty
Erroneous ranges selected by range selector	BCD converter is not functioning correctly	Check components on PC 97 or replace entire board

TABLE 5. Model 418A Troubleshooting. Also check paragraphs 4-5 and 4-6.

4-4. TROUBLESHOOTING.

a. The procedures which follow give instructions for repairing troubles which might occur in the Model 418A. Use the procedures outlined and use only specified replacement parts. Table 3 lists equipment recommended for troulbeshooting. If the trouble cannot be readily located or repaired, Keithley Instruments, Inc., can service the instrument at its complete service facilities. Contact your nearest representative.

b. Table 4 contains the more common troubles which might occur. If the repairs indicated in the Table do not clear up the trouble, find the difficulty through a circuit-by-circuit check, such as given in paragraph 4-6. Refer to the circuit description in Section 3 to find the more critical components and to determine their function in the circuit. The complete schematic diagrams, 18406F and 17931D, are found in Section 7.

4-5. PICOAMMETER CHECKOUT USING MODEL 261.

a. The Model 261 Picoampere Source is a convenient instrument to use to check out the Model 418A. The Source has outputs from 10^{-14} to 1.1×10^{-4} ampere. It has 3-digit resolution to 10^{-12} ampere. Accuracy is from $\pm 0.25\%$ at 10^{-7} ampere to $\pm 0.6\%$ at 10^{-12} ampere.

b. Connect the Model 261 to the Model 418A J101 INPUT Receptacle. Follow the instructions in paragraph 2-3 in making the connections. Also, read the Operation Section in the Model 261 Instruction Manual to insure the most accurate current outputs.

c. Dial the Model 261 output using its Range and Multiplier Switches. Check the readings on the Model 418A meter against the Model 261 output. These should agree within the accuracies of the instruments. Note the following two points:

1. The input voltage drop of the Model 418A is less than 1 millivolt. Therefore, set the Model 261 Multiplier Switches to 1.00 and set the Model 261 Range Switch to the desired output. This will result in the best case accuracy for the Model 261. At this setting, the Model 418A voltage drop is less than 1/1000 the Model 261 source voltage, which is read directly from the Multiplier Switches.

2. For output below 10^{-8} ampere and for Multiplier Switch settings other than 1.00, there is a discrepancy in the Model 261 output due to the voltage coefficient of its high megohm resistors. The Model 261 Instruction Manual contains compensations to correct for this. No compensation is needed if the Multiplier Switches are set to 1.00.

4-6. PROCEDURES TO GUIDE TROUBLESHOOTING.

a. If the instrument will not operate, check the fuse, line cord and power source. If the Input Head is remotely located, check the connection between the Head and the chassis. If these are all found satisfactory, use the following to isolate the trouble.

b. The Schematic Diagrams indicate all

tube element voltages and transistor terminal voltages referenced to chassis ground. Voltages are measured with the Model 610B; they should be ±10% of indicated value.

c. Power Supply Checkout.

1. Remove the Input Head from the main chassis to avoid accidental damage to the amplifier. Loosen the retaining screw beneath the J101 INPUT Receptacle on the rear panel and pull out the Input Head.

2. Remove transistor Q204 (Figure 3) from the circuit by removing the two retaining screws securing this transistor to the chassis plate. Turn on the instrument. Measure the voltage between chassis ground and the connector lead of Q204 with the Model 610B. Voltage should be approximately 23 volts dc.

3. Replace transistor Q204 into the circuit. Check the regulation of the power supply by using a General Radio Variac to supply the line voltage. Connect the Model 660A Voltmeter across capacitor C207 (Figure 15); vary the output voltage from the Variac from 105 to 125 volts. The voltage across the capacitor should be +15 volts dc and it should not vary more than 5 millivolts. If no voltage is present, or if the voltage is not properly regulated, check the regulator circuit. Particularly check diode D206 (Figure 15) for a short and resistor R210 (Figure 16) for an open circuit.

d. Amplifier Checkout.

1. Remove the cover from the Input Head by removing the slotted head screw on the back. If available, use the Model 4183 Remote Cable to connect the Input Head to the Picoammeter. Otherwise, insert the Input Head into the chassis, leaving the cover off.

2. Set the CONTROL Switch to LOCAL, the Range Switch to ZERO CHECK and thw METER Switch to -. Check the voltage across resistor R128 (Figure 23) with the Model 610B to check the V101 filament current. The voltage should be approximately 2.5 volts. If there is no voltage, replace the electrometer tube, V101.

3. Further troubleshooting of the amplifier is facilitated by defeating the feedback network. Set the Range Switch to 10^{-12} and short the input to ground at the J101 INPUT Receptacle. By effectively opening the feedback network, disturbances near the amplifier output will have less effect on the input stages.

4. With no feedback, any change in voltage at the input stage of the amplifier is amplified by sucessive stages, and can be measured with the Model 610B. The voltage change at the input stage can be produced by rotating the ZERO Control completely clockwise. The first stage which does not produce a voltage change comparable to those shown in Table 5 should be checked for defective components. All voltages are measured from chassis ground. Base connections to the electrometer tube are shown in Figure 10. Check voltages in the order given in Table 5.

e. Range Selector Reed Relay Checkout.

1. The function of the reed relay assemblies, K103 through K111, is to ground or connect to the chassis all unused range resistors which connect the range resistor in use to the input connector which the relay is energized. This change should be made in a break-before-make fashion.

2. If the Model 418A cannot be zeroed or if the zero control is very sensitive, this

Circuit Location	Voltage With ZERO Control Completely Counter-clockwise (volts)	Clockwise (volts)
V101 Screen	+10.5	+12.0
V101 Plate	+10.5	+ 6.6
Q101 Emitter	+10.0	+5.7
Q102 Collector	+9.1	+15.0
Q102 and Q103 Emitters	+8.9	+7.4
Q103 Base	+8.1	no change
Q104 Base	+8.7	no change
Q105 Collector	+9.3	-9.4
Q106 Emitter	+9.4	-9.2

TABLE 6. Amplifier Voltage with Feedback Loop Open. Adjusting the ZERO Control will produce the above values in a properly functioning instrument. Voltages should be checked in above order.

is a sign that the feedback voltage may be grounded. This condition will exist when a reed relay assembly is not operating properly.

3. To find the defective reed relay assembly, use an ohmmeter to check the contacts to make sure they are closed or open at the proper time.

4. If a defective relay assembly is found, order it only through Keithley Instruments, Inc.

NOTE

Use extreme care when handling the reed relay assemblies. Skin oils can destroy the high leakage resistance characteristics of the assemblies.

SECTION 5. REPLACEABLE PARTS LIST

5-1. REPLACEABLE PARTS LIST. The Replaceable Parts List describes the components of the Model 418A Picoammeter and the Model 4181 Input Head. The List gives the circuit designation, the part description, a suggested manufacturer, the manufacturer's part number and the Keithley Part Number. The last column indicates the figure picturing the part. The name and address of the manufacturers listed in the "Mfg. Code" column are in Table 7.

5-2. HOW TO ORDER PARTS.

a. For parts orders, include the instrument's model and serial number, the Keithley Part Number, the circuit designation and a description of the part. All structural parts and those parts coded for Keithley manufacture (80164) must be ordered through Keithley Instruments, Inc., or its representative. In ordering a part not listed in the Replaceable Parts List, completely describe the part, its function and its location.

b. Order parts through your nearest Keithley representative or the Sales Service Department, Keithley Instruments, Inc.

amp	ampere	Mfg.	Manufacturer
		Mil. No.	Military Type Number
CerD	Ceramic, disc	MtF	Metal Film
CerT	Ceramic, tubular	My	Mylar
Coml	Commercial		
Comp	Composition	Ω	ohm
CompV	Composition Variable		
		p	pico (10^{-12})
DCb	Deposited Carbon	Poly	Polystyrene
EAl	Electrolytic, Aluminum	Ref	Reference
ETT	Electrolytic, tantalum	reqd	Required
f	farad	μ	micro (10^{-6})
Fig.	Figure		
		v	volt
GCb	Glass enclosed carbon	Var	Variable
k	kilo (10^{3})	w	watt
		WW	Wirewound
M or meg	mega (10^{6}) or megohms	WWVar	Wirewound Variable
m	milli (10^{-3})		

TABLE 7. Abbreviation and Symbols.

MODELS 418A, 4181 REPLACEABLE PARTS LIST

(Refer to Schematic Diagrams 18406F and 17931D for circuit designations.)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Fig. Ref.
C101	0.1 µf	200 v	My	13050	SM1A	C47-.1M	
C102	22 pf	500 v	Poly	71590	CPR-22J	C138-22P	
C103	30 pf	600 v	CerT	71590	TCZ	C77-30P	
C104	330 pf	1000 v	CerD	72982	831X5R331K	C22-330P	
C105	.0022 µf	1000 v	CerD	72982	851Z5V222P	C22-.0022M	
C106	0.01 µf	300 v	CerT	01884	MPX103K3	C61-.01M	
C107	.001 µf	1000 v	CerD	72982	801Z5V102P	C22-.001M	
C108	.0022 µf	1000 v	CerD	72982	851Z5V222P	C22-.0022M	
C109	.0022 µf	1000 v	CerD	56289	5GAD22	C72-.0022M	
C110	.25 µf	400 v	My	13050	SM1A	C73-.25M	
C111	.022 µf	400 v	My	13050	SM1A	C73-.022M	
C112	*47 pf	1000 v	CerD	72982	831U2M470K	C22-47P	
C113	100 µf	25 v	ETT	05079	W100-25C2U1	C96-100M	
C114	5 pf	200 v	Poly	71590	CPR-5J	C138-5P	
C115	50 pf	200 v	Poly	71590	CPR-50J	C138-50P	
C116	500 pf	200 v	Poly	71590	CPR-500J	C138-500P	
C117	5000 pf	200 v	Poly	71590	CPR-5000J	C138-5000P	
C118	500 pf	200 v	Poly	71590	CPR-500J	C138-500P	
C119	5000 pf	200 v	Poly	71590	CPR-5000J	C138-5000P	
C120	.047 µf	200 v	My	14655	WMF2S47	C66-.47P	
C121	1.2 pf	500 v	CerT	00656	CC-20	C77-1.2P	
C122	100 µf	25 v	ETT	05079	W100-25C2U1	C96-100M	
C201	500 µf	50 v	EA1	56289	89D242	C141-500M	
C202	500 µf	50 v	EA1	56289	89D242	C141-500M	
C203	500 µf	50 v	EA1	56289	89D242	C141-500M	
C204	500 µf	25 v	EA1	56289	89D231	C94-500M	
C205	500 µf	25 v	EA1	56289	89D231	C94-500M	
C206	.01 µf	1000 v	CerD	72982	811Z5V103P	C22-.01M	
C207	500 µf	25 v	EA1	56289	89D231	C94-500M	
C208	.022 µf						
C209	22 µf						

* Nominal value, factory set.

DIODES

Circuit Desig.	Type	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
D101	Zener	1N706	12954	DZ-1	
D102	Silicon	1N645	01295	RF-14	
D103	Silicon	1N645	01295	RF-14	
D104	Silicon	1N645	01295	RF-14	
D105	Silicon	1N645	01295	RF-14	
D106	Silicon	1N645	01295	RF-14	
D107	Silicon	1N645	01295	RF-14	
D108	Silicon	1N645	01295	RF-14	
D109	Silicon	1N645	01295	RF-14	
D110	Silicon	1N645	01295	RF-14	
D111	Silicon	1N645	01295	RF-14	
D112	Silicon	1N645	01295	RF-14	
D113	Silicon	1N645	01295	RF-14	
D114	Not Used				
D115	Silicon	1N645	01295	RF-14	
D116	Not Used				
D117	Silicon	1N645	01295	RF-14	
D118	Silicon	1N645	01295	RF-14	
D201	Silicon	1N3253	02735	RF-20	
D202	Silicon	1N3253	02735	RF-20	
D203	Silicon	1N3253	02735	RF-20	
D204	Silicon	1N3253	02735	RF-20	
D205	Zener	1N718	12954	DZ-18	
D206	Silicon	1N645	01295	RF-14	
D207	Silicon	1N645	01295	RF-14	
D208	Zener	1N936	04713	DZ-5	
D301	Silicon	1N645	01295	RF-14	
D302	Silicon	1N645	01295	RF-14	
D303	Silicon	1N645	01295	RF-14	
D304	Silicon	1N645	01295	RF-14	
D305	Silicon	1N645	01295	RF-14	
D306	Silicon	1N645	01295	RF-14	
D307	Silicon	1N645	01295	RF-14	
D308	Silicon	1N645	01295	RF-14	

RELAYS

Circuit Desig.	Description	Mfg. Code	Mfg. Part No.	Keithley Part No.	Fig. Ref.
K101	Reed Relay, DPDT	70309	T154-2C	SOL-2	
K102	Double Reed Relay Assy, SPST	80164		RL-23	
K103	Double Reed Relay Assy, SPST	80164		17927B	
K104	Double Reed Relay Assy, SPST	80164		17927B	
K105	Double Reed Relay Assy, SPST	80164		17927B	
K106	Double Reed Relay Assy, SPST	80164		17927B	
K107	Double Reed Relay Assy, SPST	80164		17927B	
K108	Double Reed Relay Assy, SPST	80164		17927B	
K109	Double Reed Relay Assy, SPST	80164		17927B	
K110	Double Reed Relay Assy, SPST	80164		17927B	
K111	Double Reed Relay Assy, SPST	80164		17927B	
K112	Reed Relay, DPDT	70309	T154-2C	RL-23	
K113	Reed Relay, DPDT	70309	T154-2C	RL-23	
K114	Reed Relay, 4PDT	70309	T154-4C	RL-24	
K115	Reed Relay, DPDT	70309	T154-2C	RL-23	

MISCELLANEOUS PARTS

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Fig. Ref.
DS201	Pilot Light (Mfg. No. 39-18-372)	72619	PL-33	
F201 (117 v)	Fuse, slow blow, 1/2 amp (Mfg. Type MDL)	71400	FU-4	
F202 (234 v)	Fuse, slow blow, 1/4 amp (Mfg. No. 313.250)	75915	FU-17	
-----	Fuse Holder (Mfg. No. 342012)	75915	FH-3	
J101	Receptacle, uhf type, J101 INPUT (Mfg. No. 30116A-NT34)	95712	CS-134	
---	(F)Plug, uhf, Mate of J101, Mil. No. 49190 (Mfg. No. 83-822)	02660	CS-49	
---	Dust Cap for J101, Mil. No. MX-913/U (Mfg. No. 7901)	91737	CAP-4	
J102	Plug, 4181 Remote (Mfg. No. DA-15P), Mates with J201 and J202	71468	CS-87	
J103	PC Contacts, 18 reqd. (Mfg. No. 5201.0213), Mates with J301	91662	CS-142	
J201	Receptacle 418A Remote (Mfg. No. DA-15S), Mates with J102	71468	CS-86	
J202	Receptacle, J202 REMOTE (Mfg. No. DA-15S), Mates with J102	71460	CS-86	
J203	Receptacle, Microphone, J203 OUTPUT (Mfg. No. 80-PCZF)	02660	CS-32	
---	(F)Plug, Microphone, Mate of J203 (Mfg. No. 80-MC2M)	02660	CS-33	
J204	Socket, Remote Control (Mfg. No. XAC-34-S-F-2-A-016G)	81312	CS-147	

(F) Furnished Accessory

MISCELLANEOUS PARTS (Cont'd)

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Fig. Ref.
J301	PC Contacts 18 reqd. (Mfg. No. 5101.0613), Mates with J103	91662	CS-143	
M201	Meter	80164	ME-46	
P201	Cord Set, 6 feet (Mfg. No. 4638-13)	93656	CO-5	
S201	Slide Switch, 117-234 v	80164	SW-151	
S202	Push Switch, ZERO CHECK	80164	SW-150	
---	Knob Assembly, Zero Check Switch	80164		
S203	Rotary Switch, CONTROL	80164	SW-184	
---	Knob Assembly, Control Switch	80164		
S204	Rotary Switch, Range	80164	SW-183	
---	Knob Assembly, Range Switch	80164		
S205	Rotary Switch, METER	80164	SW-113	
---	Knob Assembly, Meter Switch	80164		
S206	Switch, DAMPING	80164		
---	Knob Assembly, Damping Control	80164		
---	Knob Assembly, Zero Control	80164		
T201	Transformer	80164	TR-79	

RESISTORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Fig. Ref.
R101	10^{12} Ω	+3%, -0%	GCb	63060	RX-1	R20-10^{12}	
R102	10^{11} Ω	+3%, -0%	GCb	63060	RX-1	R20-10^{11}	
R103	10^{10} Ω	+3%, -0%	GCb	63060	RX-1	R20-10^{10}	
R104	10^{9} Ω	+3%, -0%	GCb	63060	RX-1	R20-10^{9}	
R105	100 MΩ	1%, 2 w	DCb	91637	DC-2	R14-100M	
R106	10 MΩ	1%, 1 w	DCb	91637	DC-1	R13-10M	
R107	1 MΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-1M	
R108	100 kΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-100K	
R109	2 MΩ	30%, 1/4 w	CompV	71450	UPM-45	RP12-2M	
R110	68 kΩ	10%, 1/2 w	Comp	01121	EB	R1-68K	
R111	2 MΩ	30%, 1/4 w	CompV	71450	UPM-45	RP12-2M	
R112	2 MΩ	30%, 1/4 w	CompV	71450	UPM-45	RP12-2M	
R113	180 kΩ	10%, 1/2 w	Comp	01121	EB	R1-180K	
R114	330 kΩ	10%, 1/2 w	Comp	01121	EB	R1-330K	
R115	1 kΩ	.5%, 1/2 w	MtF	07716	CEC	R61-1K	

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Fig. Ref.
R116	500 Ω	.5%, 1/4 w	MtF	07716	CEB	R75-500	
R117	10 kΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-10K	
R118	30 kΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-30K	
R119	1 kΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-1K	
R120	3 kΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-3K	
R121	300 Ω	1%, 1/2 w	DCb	79727	CFE-15	R12-300	
R122	22 MΩ	10%, 1/2 w	Comp	01121	EB	R1-22M	
R123	*33 Ω	10%, 1/2 w	Comp	01121	EB	R1-33	
R124	121 kΩ	1%, 1 w	MtF	07716	CEC	R94-121K	
R125	1.2 kΩ	1%, 1/2 w	WW	01686	E-30	R58-1.2K	
R126	1 kΩ	1%, 1/2 w	WW	01686	E-30	R58-1K	
R127	1 kΩ	10%, 1/2 w	WWVar	80294	3067S	RP35-1K	
R128	250 Ω	1%, 1/2 w	WW	01686	E-30	R58-250	
R129	22 kΩ	10%, 1/2 w	Comp	01121	EB	R1-22K	
R130	75 kΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-75K	
R131	*470 Ω	10%, 1/2 w	Comp	01121	EB	R1-470	
R132	10 kΩ	10%, 1/2 w	Comp	01121	EB	R1-10K	
R133	6.8 kΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-6.8K	
R134	*15 Ω	10%, 1/2 w	Comp	01121	EB	R1-15	
R135	6.8 kΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-6.8K	
R136	75 kΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-75K	
R137	4.7 kΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-4.7K	
R138	6 kΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-6K	
R139	Not Used						
R140	1.8 kΩ	10%, 1/2 w	Comp	01121	EB	R1-1.8K	
R141	22 Ω	10%, 1/2 w	Comp	01121	EB	R1-22	
R142	560 Ω	10%, 2 w	Comp	01121	HB	R3-560	
R143	10 MΩ	10%, 1/2 w	Comp	01121	EB	R1-10M	
R144	47 Ω	10%, 1/2 w	Comp	01121	EB	R1-47	
R145	47 Ω	10%, 1/2 w	Comp	01121	EB	R1-47	
R146	1.5 kΩ	10%, 1/4 w	Comp	01121	CB	R76-1.5K	
R147	1 kΩ	10%, 1/2 w	Comp	01121	EB	R1-1K	
R148	Not Used						
R149	4.7 kΩ	10%, 1/2 w	Comp	01121	EB	R1-4.7K	
R201	3 Ω	.1%, 2 w	WW	01686	7070	R92-3	
R202	3 Ω	.1%, 2 w	WW	01686	7070	R92-3	
R203	1.5 kΩ	10%, 1/2 w	Comp	01121	EB	R1-1.5K	
R204	550 Ω	1%, 1/2 w	WW	01686	E-30	R58-550	
R205	200 Ω	3%, 5 w	WWVar	73138	A	RP4-200	
R206	10 kΩ	10%, 1/2 w	Comp	01121	EB	R1-10K	
R207	470 Ω	1%, 1/2 w	WW	01686	E-30	R58-470	

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Fig. Ref.
R208	10 kΩ	10%, 1/2 w	Comp	01121	EB	R1-10K	
R209	820 Ω	10%, 1/2 w	Comp	01121	EB	R1-820	
R210	1.0 Ω	1%, 1/2 w	DCb	79727	CFE-15	R12-1	
R211	1.2 kΩ	10%, 1/2 w	Comp	01121	EB	R1-1.2K	
R212	680 Ω	10%, 1/2 w	Comp	01121	EB	R1-680	
R213	3.9 kΩ	10%, 1/2 w	Comp	01121	EB	R1-3.9K	
R214	3.9 kΩ	10%, 1/2 w	Comp	01121	EB	R1-3.9K	
R215	600 Ω	1%, 1/2 w	DCb	79727	CFE-15	R12-600	
R216	900 Ω	1%, 1/2 w	DCb	79727	CFE-15	R12-900	
R217	2.5 kΩ	1%, 1/2 w	DCb	79727	CFE-15	R12-2.5K	
R218	1 kΩ	10%, 5 w	WWVar	71450	AW	RP34-1K	
R219	Not Used						
R220	Not Used						
R221	1.5 kΩ	10%, 1/2 w	Comp	01121	EB	R1-150	
R222	3 kΩ	30%, 1/6 w	CompV	71450	45	RP36-3K	
R301	4.7 kΩ	10%, 1/2 w	Comp	01121	EB	R1-4.7K	
R302	4.7 kΩ	10%, 1/2 w	Comp	01121	EB	R1-4.7K	
R303	6.8 kΩ	10%, 1/2 w	Comp	01121	EB	R1-6.8K	
R304	4.7 kΩ	10%, 1/2 w	Comp	01121	EB	R1-4.7K	
R305	4.7 kΩ	10%, 1/2 w	Comp	01121	EB	R1-4.7K	
R306	6.8 kΩ	10%, 1/2 w	Comp	01121	EB	R1-6.8K	
R307	4.7 kΩ	10%, 1/2 w	Comp	01121	EB	R1-4.7K	
R308	6.8 kΩ	10%, 1/2 w	Comp	01121	EB	R1-6.8K	
R309	4.7 kΩ	10%, 1/2 w	Comp	01121	EB	R1-4.7K	
R310	1 kΩ	10%, 1/2 w	Comp	01121	EB	R1-1K	
R311	4.7 kΩ	10%, 1/2 w	Comp	01121	EB	R1-4.7K	
R312	6.8 kΩ	10%, 1/2 w	Comp	01121	EB	R1-6.8K	
R313	3.9 kΩ	10%, 1/2 w	Comp	01121	EB	R1-3.9K	
R314	2.2 kΩ	10%, 1/2 w	Comp	01121	EB	R1-2.2K	

TRANSISTORS

Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
Q101	A1294	73445	TG-29	
Q102	A1294	73445	TG-29	
Q103	A1294	73445	TG-29	
Q104	A1294	73445	TG-29	
Q105	2N651	04713	TG-9	
Q106	2N1183	02735	TG-11	

TRANSISTORS (Cont'd)

Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
Q201	2N1535	04713	TG-7	
Q202	2N1381	01295	TG-8	
Q203	2N1183	02735	TG-11	
Q204	2N1535	04713	TG-7	
Q205	2N1381	01295	TG-8	
Q206	2N1381	01295	TG-8	
Q207	2N1381	01295	TG-8	
Q301	2N1381	01295	TG-8	
Q302	2N1381	01295	TG-8	
Q303	2N1381	01295	TG-8	
Q304	2N1381	01295	TG-8	
Q305	2N1381	01295	TG-8	
Q306	2N1381	01295	TG-8	
Q307	2N1381	01295	TG-8	
Q308	2N1381	01295	TG-8	
Q309	2N1381	01295	TG-8	
Q310	2N1381	01295	TG-8	
Q311	2N1381	01295	TG-8	
Q312	2N1381	01295	TG-8	
Q313	2N1381	01295	TG-8	
Q314	2N1381	01295	TG-8	
Q315	2N1381	01295	TG-8	
Q316	2N1381	01295	TG-8	
Q317	2N1381	01295	TG-8	
Q318	2N1381	01295	TG-8	
Q319	2N1381	01295	TG-8	
Q320	2N1381	01295	TG-8	
Q321	2N1381	01295	TG-8	
Q322	2N1381	01295	TG-8	
Q323	2N1381	01295	TG-8	
Q324	2N1381	01295	TG-8	

VACUUM TUBES

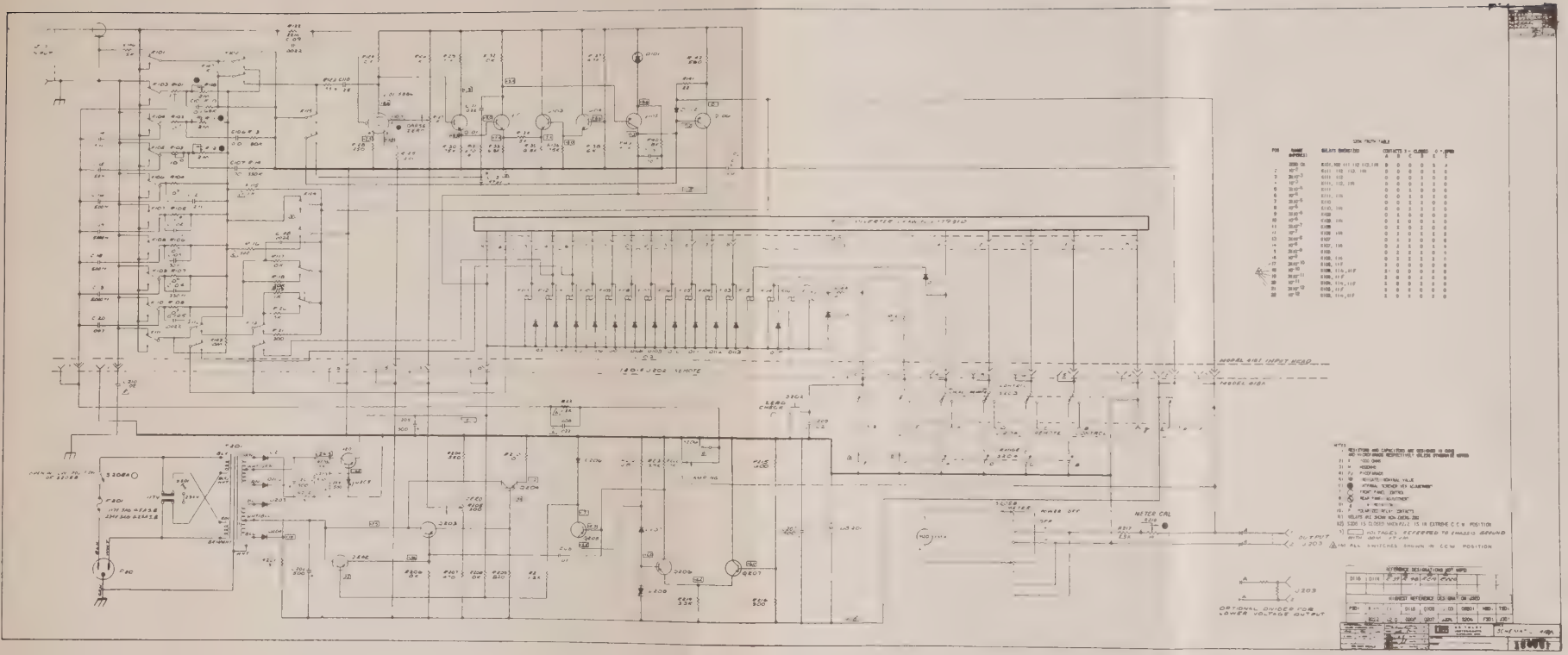
Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
V101	5886	80164	EV-5886-2X	

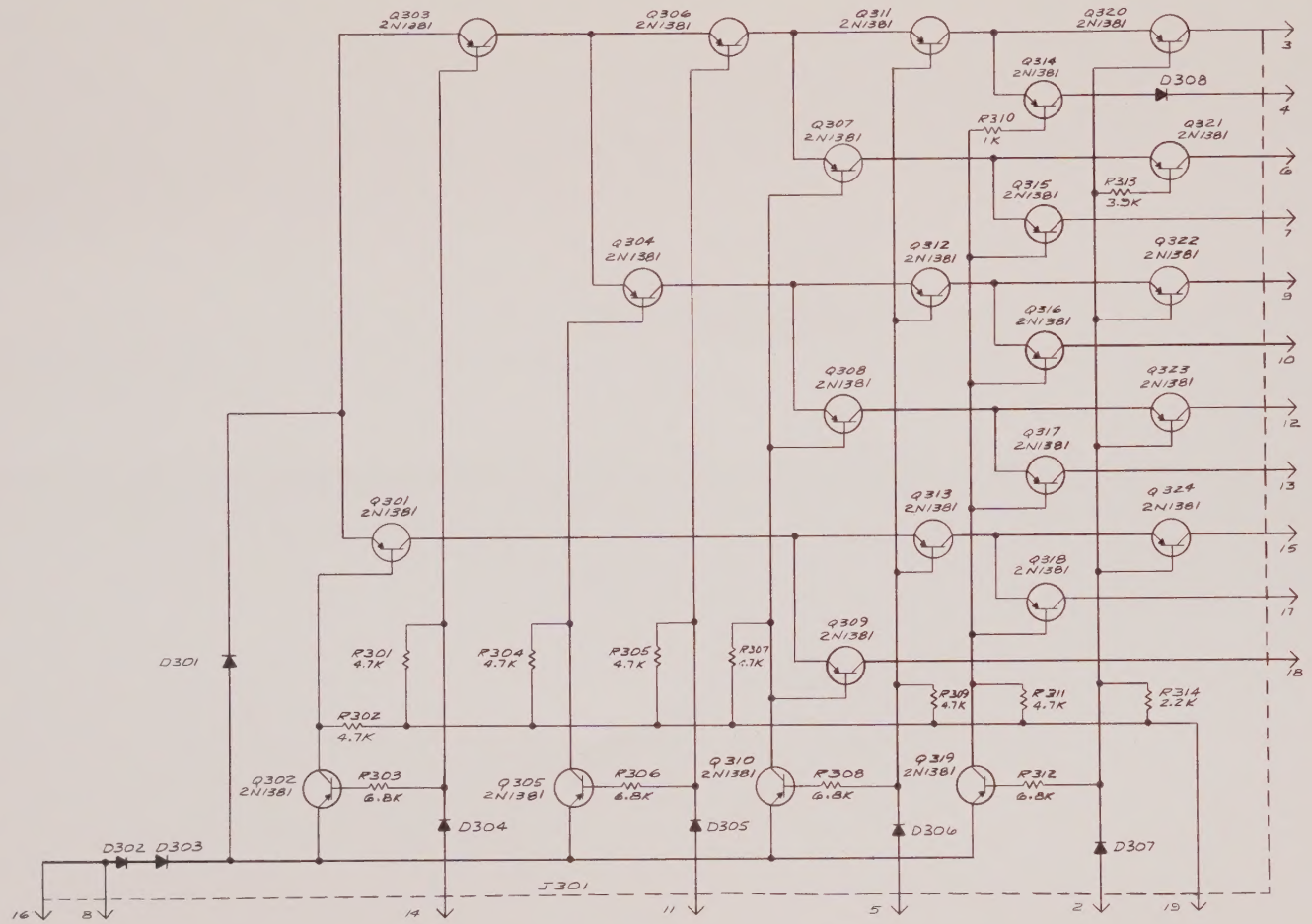
00656	Aerovox Corp. New Bedford, Mass.
01121	Allen-Bradley Corp. Milwaukee, Wis.
01295	Texas Instruments, Inc. Semiconductor-Components Division Dallas, Tex.
01686	RCL Electronics, Inc. Riverside, N. J.
01884	Dearborn Electronic Laboratories, Inc. Orlando, Fla.
02660	Amphenol-Borg Electronics Corp. Broadview, Chicago, Illinois
02735	Radio Corp. of America Commercial Receiving Tube and Semiconductor Division Somerville, N. J.
04713	Motorola, Inc. Semiconductor Products Division Phoenix, Arizona
05079	Tansitor Electronics, Inc. Bennington, Vt.
07716	International Resistance Co. Burlington, Iowa
12954	Dickson Electronics Corp. Scottsdale, Ariz.
13050	Potter Co. Wesson, Miss.
14655	Cornell-Dubilier Electric Corp. Newark, N. J.
56289	Sprague Electric Co. North Adams, Mass.
63060	Victoreen Instrument Co. Cleveland, Ohio
70309	Allied Control Co., Inc. New York, N. Y.
71400	Bussmann Mfg. Div. of McGraw-Edison Co. St. Louis, Mo.
71450	CTS Corp. Elkhart, Ind.
71468	ITT Cannon Electric, Inc. Los Angeles, Calif.
71590	Centralab Division of Globe-Union, Inc. Milwaukee, Wis.
72619	Dialight Corp. Brooklyn, N. Y.
72982	Erie Technological Products, Inc. Erie, Pa.
73138	Helipot Division of Beckman Instruments, Inc. Fullerton, Calif.
73445	Amperex Electronic Co. Division of North American Philips Co., Inc. Hicksville, N. Y.
75915	Littelfuse, Inc. Des Plaines, Ill.
79727	Continental-Wirt Electronics Corp. Philadelphia, Pa.
80164	Keithley Instruments, Inc. Cleveland, Ohio
80294	Bourns Laboratories, Inc. Riverside, Calif.
81312	Winchester Electronics Co., Inc. Norwalk, Conn.
83125	General Instrument Corp. Capacitor Division Darlington, S. C.
91637	Dale Electronics, Inc. Columbus, Nebr.
91662	Elco Corp. Willow Grove, Pa.

TABLE 8. Code List of Suggested Manufacturers. (Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1.)

91737	Gremar Mfg. Co., Inc. Wakefield, Mass.	95348	Gordos Corp. Bloomfield, N. J.
93656	Electric Cord Co. Caldwell, N. J.	95712	Dage Electric Co., Inc. Franklin, Ind.

TABLE 8. Code List of Suggested Manufacturers. (Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1.)





NOTES:
1. ALL RESISTANCE AND CAPACITANCE SHALL BE DESIGNATED IN OHMS AND MICROFARADS RESPECTIVELY UNLESS OTHERWISE NOTED.
2. K- 1000 OHMS
3. M- MEGOHMS

HIGHEST REFERENCE DESIGNATION USED

R314	Q324	D308	J301				

DO NOT SCALE

KEITHLEY INSTRUMENTS CLEVELAND, OHIO

TITLE: SCHEMATIC, BCD CONVERTOR

PART NUMBER: 17931D

KEITHLEY INSTRUMENTS, INC.
12415 EUCLID AVENUE
CLEVELAND, OHIO 44106